

Teaching Science Using Guided Inquiry as the Central Theme: A Professional Development Model for High School Science Teachers

Abstract

The author describes a professional development model for high school science teachers based on the framework of inquiry and science standards. The 'Learn-Teach-Assess Inquiry' model focuses on guided inquiry labs as the central theme and builds on these labs to reinforce science concepts and abilities to understand and engage in inquiry in accordance with national/state science standards. A professional development model for high school science teachers based on the framework of inquiry and National Science Education Standards has been developed and field tested for three years. This model requires intensive involvement of teachers and project personnel in workshops, material development, and round-the-year follow-up school visits for a three-year cycle.

The professional development improves the ability of teachers to do and understand inquiry. Consequently, teachers organize more guided inquiry labs and post-lab discussion and motivate students to ask more questions in their classrooms.

Key words: professional development, guided inquiry labs, inquiry teaching, national science education standards

Introduction

Inquiry has been envisioned in the *National Science Education Standards* (NSES) as a pedagogical method that models scientific practice and encourages students to gain content knowledge. Scientific inquiry is defined by NSES as follows (National Research Council [NRC], 1996):

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (p. 23).

The fundamental abilities to do inquiry in grades 9-12 are listed in the *Inquiry and the National Science Education Standards* as follows (NRC, 2000):

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.

- Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations. (p. 19)

Professional Development and NSES

Most teachers of science do not get the opportunity to learn science through inquiry, yet the NSES professional development standards require their students to learn science content through the process of inquiry. Therefore, direct experience and continued practice with the processes of inquiry are needed in order to develop in teachers the knowledge and skills related to inquiry that will enable them to effectively employ this technique in their classrooms.

The NSES content standards in inquiry pertain to abilities understand and engage in inquiry. Direct experience and continued practice with the processes of inquiry are needed in order to develop knowledge and skills about inquiry. Teachers need to introduce students to the fundamental elements of inquiry and help students engage in and reflect on the processes they use to do inquiry.

Inquiry-related knowledge and classroom experience must be combined with subject matter knowledge in ways that allow students to use scientific reasoning and critical thinking to develop their understanding of science. Inquiry also requires learners to be able to determine answers to questions such as: “What counts? What data do we keep? What data do we discard? What patterns exist in the data? Are these patterns appropriate for this inquiry? What explanations account for the patterns? Is one explanation better than another?” (NRC, 2000, p. 18). Teachers need to be well versed in inquiry, but unfortunately many of them do not get the opportunity to learn science through inquiry during their grade school and college education. A survey shows that 91% of universities in the United States use direct laboratory instruction in general chemistry (Abraham et al., 1997). Similarly, almost half of surveyed high school chemistry teachers indicate that they do not use any inquiry laboratory exercises in their classroom (Deters, 2005). Professional development standards require that schools provide students the opportunity to learn essential science content through the process of inquiry (NRC, 1996). In order to accomplish this, teachers must have a sound content knowledge base that includes an understanding of the nature of inquiry, its central role in science, and the skills and processes of inquiry. The standards emphasize inquiry into teaching and learning, and they place a reduced emphasis on lecture. These standards reinforce the expectation that science is to be learned through investigation and inquiry rather than lecture and reading.

Inquiry and Professional Development Models

Various professional development (PD) models on inquiry teaching have been reported in the literature. Professional development programs must teach inquiry knowledge as well as assess and address teachers’ core teaching conceptions (Lotter, Harwood, & Bonner, 2007). Pine et al. (2006) reported that historically low achieving students could succeed in standards-based inquiry science when the curriculum was developed and aligned with professional development and district policies. Large-scale, high-quality, intensive training within a context of standards-based systemic reform could be a powerful mechanism for sustained impact on teachers (Supovitz, Mayer, & Kahle, 2000). A meta-analysis of 61 studies (Schroeder, Scott, Tolsom, Huang, & Lee, 2007) identified enhanced context, collaborative learning, and inquiry as the most effective teaching strategies. A significant difference was found in cognitive activities and questioning skills between teachers in professional development programs modeling authentic inquiry and programs that simulated inquiry (Hanegan, Friden, & Nelson, 2009).

Other effective professional development models include: professional learning communities (Nelson, 2009), guided instruction (Kirschner, Sweller, & Clark, 2006), modeling instruction based on conceptual models of physical phenomena (Jackson, Dukerich, & Hestenes, 2008), Iowa Chautauqua Science – Technology – Society program for in-service teachers (Yager & Akcay, 2007), Content-Based collaborative inquiry model (Zech, Gause-Vega, Bray, Secules, & Goldman, 2000), and

NSF funded research experiences for teachers (Blanchard, Southerland, & Granger, 2009).

Theoretical Framework and Objectives of the Study

A teacher professional development model ‘Learn-Teach-Assess Inquiry’ (LTAI), which is based on the theoretical framework of inquiry as envisioned in the NSES as well as collaborative learning principles, has been developed and field tested. The LTAI model focuses on guided inquiry labs as the central theme and builds on these labs to reinforce science concepts and abilities to understand and engage in inquiry in accordance with national/state science standards. The PD program requires the intensive involvement of teachers and project personnel in workshops, material development, and round-the-year follow-up school visits as part of a three-year cycle. The PD is conducted slowly but intensively over a period of time in order to build abilities to understand and engage in inquiry. This is done in part through the use of the apprenticeship model concept of imparting and developing skills. Other important factors of this model include giving teachers enough time to learn at their own pace and providing an opportunity to internalize inquiry processes and become comfortable using inquiry in the classroom. The essential features of classroom inquiry and their variations have been described in the NSES (Table 1). Table 1 shows the guiding framework of procedures considered as guided inquiry in the present study, and the areas marked in bold are considered to be attributes of guided inquiry according to the LTAI model.

The major objectives of this PD program are:

1. Development of guided inquiry labs in collaboration with teachers.
2. Development of flexible lesson plans connecting guided inquiry labs to concepts, skills, application in daily life, and national/state science education standards.
3. Development of questioning and post-lab discussion abilities
4. Field testing of the guided inquiry labs by teachers in their classrooms
5. Modification of the labs based on field testing, and
6. Assessment of the effect guided inquiry teaching has on student content knowledge as well as students' abilities

to understand and engage in inquiry.

Objectives 1 through 5 are discussed in this paper. The last objective, which has to do with assessing the effect of guided inquiry on student learning of content knowledge, is in progress as a part of the third year study and will be reported separately.

Methods

Participants.

A small group of 10 teachers from Muscogee, Harris, and Troup counties in southwestern Georgia were selected based on their willingness and commitment to participate in this PD program for three consecutive years. The consent of principals and school districts was also obtained for participation in this long term study. All teachers are from similar socio-economic urban/rural high schools

with teaching experience ranging from 5 to 15 years. Each has a teaching degree in the field and also a MS degree in science education. Seven teachers teach high school physical science and three teach chemistry. Teachers can use the PD workshop hours as either a graduate course or a professional learning unit. Each teacher is given a stipend and travel expenses for summer and academic year workshops. Supplies, including inquiry lab kits, are also provided to each teacher.

Project team.

The project team is made up of the author as PI, assisted by a science education faculty member from the College of Education, a graduate assistant, and two high school science teachers who served as part-time research assistants.

Table 1: Essential Features of Classroom Inquiry and Their Variations

Essential Feature	Variations			
1. Learner investigates scientifically oriented questions	Learner poses a question	Learner selects a question from a pre-established list, or poses new questions	Learner sharpens or clarifies the question provided by teacher, materials, or another source	Learner engages in evaluating the question provided by teacher, materials, or another source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner is directed to collect certain data	Learner is given data and asked to analyze it	Learner is given data and directed how to analyze it
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner is guided in the process of formulating explanations based on evidence	Learner is told possible ways to use evidence to formulate explanations	Learner is provided with evidence and told how to use evidence to formulate explanations
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner is directed toward areas and sources of scientific knowledge	Learner is given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner is coached in development of communication that conveys justification for explanations	Learner is provided broad guidelines to use that sharpen communication	Learner is given steps and procedures for communication

More ————— Amount of Learner Self-Direction ————— Less
 Less ————— Amount of Direction from Teacher or Material ————— More

PD program.

The components of this three-year professional development program take place as follows:

Year 1: Teachers attend a 40-hour summer workshop over the course of 10 days, followed by academic year workshops that take place two hours per week for 10 weeks during both the fall and spring semesters. The schedule includes content updates, development of guided inquiry labs, practice using guided inquiry to develop abilities to understand and engage in inquiry, and development of questions and post-lab discussion strategies. Year 1 uses the apprenticeship model concept to develop inquiry abilities in teachers.

Year 2: PD continues with field testing of labs and lesson plans in project classrooms. This is followed up during the workshops with presentation of field test reports and discussion, and this feedback is used to modify the labs and lesson plans.

Year 3: Project teachers use guided inquiry labs as the central theme to teach physical science/chemistry in high schools for two semesters using pre- and post- design and assessment instruments. The last year is focused on studying the effect of PD on student content knowledge as well as students' abilities to understand and engage in inquiry.

Instruments.

Science inquiry test: This 15-item test measured abilities to understand and engage in inquiry. Released tests of the National Assessment of Educational Progress (NAEP) and other sources were used to develop the test items. A pre-test was administered in the fall semester of the second year of PD, and the post-test took place at the end of the academic

year (spring semester). The validity and reliability of the test were determined using standard procedures.

Classroom observation.

Classroom observation is done by the project team to assess the extent to which guided inquiry is implemented, including the amount of post-lab discussion and questioning engaged in by students. Each teacher is observed at least four times each semester, and inter-rater reliability was determined by standard procedures to be very high (0.80).

Teacher reflection.

Teachers maintain a journal of their observations about implementation of guided inquiry labs, including the number of guided inquiry labs and post-lab discussions done each semester, as well as the frequency and types of questions asked by students. Teachers present their reflections during workshops.

Classroom observation and teacher reflection data are collated to calculate percentage of guided inquiry labs and post-lab discussion topics covered each semester, as well as the frequencies of questions asked by students.

Guided inquiry labs.

Twelve guided inquiry labs have been developed in collaboration with project teachers by converting previously used "cookbook" labs and by selecting new inquiry-based labs. The labs have been selected from high school curricula in physical science and chemistry and aligned to the Georgia Performance Standards. Examples of content areas include: introduction to the scientific method, chemical and physical changes, elements, compounds and mixtures,

separation of mixtures, density measurements, single replacement reactions and metal reactivity, stoichiometry, periodic trends and properties of elements, rate of a reaction, and factors affecting rate of a reaction. Two sample guided inquiry labs are given in Tables 2 and 3.

Results and Discussion

Guided inquiry labs.

In order to lead meaningful inquiry activities, teachers need adequate subject matter content knowledge. But, content knowledge alone is not sufficient. Teachers must develop abilities to understand and engage in inquiry before they can effectively teach their students how to engage in the process of inquiry.

Prior to joining this PD program, the project teachers attended several district/state level workshops/seminars on inquiry teaching. The district/state level workshops/seminars had concentrated on the theory of teaching through inquiry, but included little or no inquiry-based activities. Similar observations have been made by other researchers as well (Abraham et al., 1997; Deters 2005). Roehrig and Luft (2004) reported on a study of 10 beginning chemistry teachers with undergraduate experience that consisted of traditional testing and laboratory activities designed to master specific laboratory techniques. Their high school classroom teaching was modeled on their personal experiences as undergraduates and graduate students. These teachers did not have access to any inquiry-based chemistry materials and struggled to translate their knowledge of chemistry into specific inquiry-based chemistry lessons.

Subject matter content knowledge is an essential requirement for doing meaningful inquiry. Hence, it is ensured during PD workshops that teachers have adequate content knowledge in physical science/chemistry. However, content knowledge alone is not sufficient. As stated in the NSES: "Prospective and practicing teachers must take science courses in which they learn science through inquiry, having the same opportunities as their students will have to develop understanding" (NRC,1996, p.60). Apart from content knowledge, teachers must have the abilities to understand and engage in inquiry.

The PD program starts with a simple guided inquiry lab that introduces a research question, hypothesis, and experiment (Table 2). Teachers are asked to generate their hypotheses regarding the research question. Then, they do the experiment to test their hypotheses and formulate new ones (if needed) based on experimental evidence. Initially, about 40% of teachers chose the correct

Table 2. Introduction to guided inquiry: Research question, hypothesis, and experiment

Research question:

An ice cube is put in each of the following:

- A. Tightly wrapped in aluminum foil
- B. In a tin can
- C. In a glass jar
- D. In a glass jar that is completely covered in aluminum foil

In which case would the ice cube melt the LEAST over a period of 30 minutes?

Your hypothesis: A/B/C/D

Reason for your hypothesis:

Do the experiment to test your hypothesis.

What was your observation and conclusion?

Did the experiment support your hypothesis?

If not, what is your new hypothesis?

What are the reasons for changing your hypothesis?

What did you learn about science inquiry from this activity?

response (C). The follow-up discussion revealed that 60% of teachers did not have a clear understanding of the concepts involved (specific heat and conduction of heat).

Another example of a guided inquiry lab for the teachers is given in Table 3. The purpose of this lab is to guide the teachers through the stages of a meaningful inquiry on a chemical reaction that highlights the importance of observation, questioning, and use of science knowledge for further inquiry. This lab demonstrates how content knowledge in

chemistry could be integrated with inquiry skills to develop abilities and understanding about inquiry.

Abilities to do and understand inquiry.

The abilities of teachers to do and understand inquiry is assessed through a pre-test and post-test on the subject of inquiry. The results show a 30% increase in the mean scores at the end of one academic year. The progression of teachers on inquiry abilities is formatively assessed throughout the academic year using

Table 3. A guided inquiry lab in physical science/chemistry:

What happens when you burn magnesium metal in air? A guided inquiry lab

Hint for teachers: This is not a lesson plan. You will develop flexible lesson plans for teaching this topic after you do the investigation yourself. Identify the national and state science education standards. This guided inquiry lab is to be done by students with minimal teacher support. So, have patience and help students to explore and come up with their own questions, results, and possible explanations. Provide hints/help when needed. Hints are provided in parentheses. During PD workshop, you will complete this lab.

Objectives:

1. To understand the process of investigative approach to science inquiry
2. To understand how knowledge of content and skills are important to conducting inquiry processes
3. To identify content, process, and nature of science standards which could be taught using this lab.

Guided inquiry procedure :

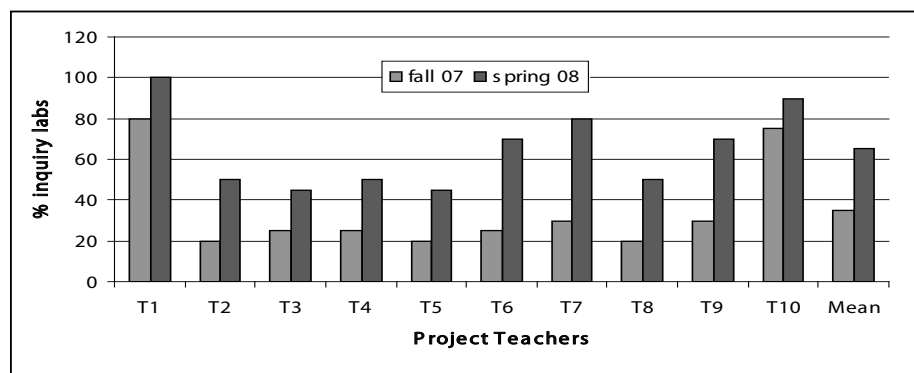
1. Take a piece of magnesium ribbon (one inch). Look at the color and other physical properties before burning: (Grey/silvery, thin and strong strip, can be twisted)
2. Observation is a very important step in science inquiry. You will make observations while doing this lab. What equipment do you need? (Mg ribbon, tongs, Bunsen burner, test tubes, diluted hydrochloric acid, watch glass, safety goggles)
3. Burn the magnesium and record all observations. (Bright flame, product color looks different from magnesium metal, color is white or there is a mix of white/grey powder)
4. What questions do you have based on these observations? Write down these questions. (Lead questions: What are the major observations? Is burning magnesium a chemical or physical change, or both? Is the product different from the reactant magnesium metal?)
5. Selecting one question at a time, discuss these topics in your group and suggest a method and procedure you could use to investigate that question. Discuss your proposed methods with the teacher and finalize your plan.
6. Question: Is the product different from reactant magnesium metal? Place small amounts of magnesium metal and the product left after burning in two separate test tubes. Add 10 drops of diluted hydrochloric acid to each test tube. Observe and record what happens. (Hint- Possible observation: Gas comes out (fizzing occurs) when magnesium metal reacts with hydrochloric acid in the test tube and no fizzing takes place in the test tube containing the product. The gas being released is hydrogen. To verify this, put a burning match over the mouth of each test tube. If hydrogen gas is produced, a popping sound will be heard.)

continued on next page.

Table 3, *continued*

7. What are your inferences? Does the product contain magnesium metal? (The product does not have magnesium metal, since it did not react with hydrochloric acid).
8. Question: What does the product contain? (Possible student questions/hypotheses: Does it contain Mg as metal? Answer: No. What happened to the magnesium metal? Hypotheses: It evaporated to air; converted to another form; the product does not contain magnesium.)
9. Does the product contain magnesium in some other form? If yes, in what form? (Discuss this topic in groups and then generate a whole class discussion. What do we do to investigate the possibility that magnesium is present in some other form in the product? Discuss with students the need for content knowledge and abilities to engage in inquiry. Then demonstrate to students a lab test that detects magnesium ions in a known sample and perform the same test on the residue left after burning magnesium. If the test shows the same results in both known and unknown samples, what do you infer? (The unknown has magnesium ion.)
10. What do you conclude? (The product contains magnesium ion.)
11. Challenge students to come up with a possible explanation of how the magnesium metal became the magnesium ion in the solid product after burning in air. Is this a chemical or physical change?
12. Use this lab to develop concepts of chemical and physical changes, chemical reactions, ionic bonding, and the transfer of electrons from magnesium to oxygen during the formation of magnesium oxide.
13. Extension of this lab: What is the empirical formula of the product formed after burning Mg?

Figure1. Increase in guided inquiry labs from fall 07 to spring 08



classroom observation and teacher reflection data. The results are shown in Figure 1 and Table 4.

A lab is considered to be guided inquiry if it fulfills some features of inquiry as given in Table 1 and is not a totally teacher-centered lab. The project teachers started teaching using the inquiry labs in fall 2007 after receiving one year PD on developing and doing the labs themselves during the 2006-2007 academic year of the project. An average of about 25% of labs done during the first semester used guided inquiry. Although this is not great progress, it is definitely impressive. An increase

in guided inquiry labs by 25-50% (after excepting Teacher T4, who was still struggling with inquiry after a year) from fall to spring semester is quite impressive. The mean increase was 33%, and there was a large effect size.

There is no silver bullet for inquiry: Science educators need to have patience and understand the factors that impede implementation and transition to inquiry.

It is rather frustrating to note that even after one full year of intensive PD and one semester of teaching using inquiry, the mean percentage

of labs conducted using guided inquiry was only 58%. Classroom observation and teacher reflection provide some reasons for this lack of implementation: time constraints (inquiry labs require more lab time), pressure to structure classes in a way that maximizes course completion, pressure to concentrate on preparing students for state level testing, and difficulties associated with motivating all students to participate in inquiry. Johnson (2006) reported that even with effective professional development, science teachers still encounter technical, political, and cultural barriers to the implementation of inquiry. More support is required for professional development efforts to be successful, such as resources and time, as well as administrative buy-in and support.

Post-lab discussion.

Effective post-lab discussion is an important component of this PD model. It is based on the premise that post-lab discussion will enhance cooperative and collaborative learning in the spirit of inquiry, as well as provide students with experience sharing and presenting their inquiry data and evidences. This experience is expected to help students to know and appreciate the ways that scientists share and present their findings (NRC, 1996). The PD model also provides guidelines for teachers on ways to organize post-lab discussion (Table 5).

The extent to which teachers organize post-lab discussion is monitored through classroom observations and teacher reflections. The changes in percentage of post-lab discussions during fall 2007 and spring 2008 are given in Figure 2 and Table 5.

Table 4. Change in % inquiry labs conducted during fall 07 and spring 08

Teacher/Statistics	Fall 2007 % inquiry labs	Spring 2008 % Inquiry labs	Difference % inquiry labs
T1	25	50	25
T2	20	40	20
T3	25	50	25
T4	25	40	15
T5	30	70	40
T6	30	60	30
T7	25	55	30
T8	30	75	45
T9	20	70	50
T10	25	75	50
Mean	25.5	58.5	33.0
SD	3.7	13.5	
Effect size			3.33

A 20-50% increase in post-lab discussion is observed after one semester of inquiry teaching. The mean increase from fall to spring semester was 30% with an effect size of 1.4. Some teachers (T1, T10,) were doing a substantial amount of post-lab discussion in the fall semester and maintained or increased the level

further in spring, but even those teachers that had not previously been focusing on post-lab discussions showed an impressive change in this area. These results show that the PD model is effective in developing experience and confidence in teachers to organize effective post-lab discussion in their classrooms.

Table 5. Post-lab discussion

1. Organize a post-lab discussion for 30 minutes after each guided inquiry lab.
2. First, organize group discussion on lab results and interpretation, followed by presentation of group reports to the whole class.
3. Ask students why different groups think different ways and how they would resolve the differences. Encourage each group to synthesize their findings and conclusions based on whole class discussion.
4. Then you (the teacher) should summarize the post-lab discussion and offer your ideas/comments, being sure to connect the inquiry-based lab activities to the academic content being covered.
5. Wrap up post-lab discussion with questions such as:
 - Q 1. What are "data" in your lab today?
 - Q 2. What are the evidences you collected?
 - Q 3. If a scientist were to perform the lab you did today, would he/she complete it in the same way?
If not, what do you think the scientist would do? (Hint: Scientists follow similar procedures to discuss and share their viewpoints)
 - Q 4. Do you see any similarity between you and a scientist? (Hints: Both raise questions, hypothesize, design experiments, collect data and evidences, and develop explanations/theories)

Abilities to ask questions.

Development of abilities to ask questions is an important part of inquiry teaching and learning (NRC, 1996, 2000). This is also a major objective of this PD model. The project teachers get opportunities to ask questions while doing inquiry labs and post-lab discussion during PD workshops. It is expected that teachers will promote the development of abilities related to questioning in their classrooms while teaching using guided inquiry labs. The frequency of questions asked is rated as rarely, sometimes, or frequently through classroom observations and teacher reflections. The results are shown in Figure 3.

These results are encouraging because the percentage of 'frequently' and 'sometimes' asked questions increased between the fall 2007 and spring 2008 semesters. Even in fall 2007, 30% of students asked questions frequently, and the proportion increased to 60% in the spring. The data shows that the PD model is effective at helping teachers to motivate students to ask more questions, which is an essential part of inquiry-based learning.

Preliminary student data.

The preliminary data from two project schools' chemistry classes (Teacher T1 and T10; student samples 50) on student pre- and post-test scores in science inquiry show an increase of 20%. An attitude survey on inquiry teaching also provides some interesting results: 83% of students like guided inquiry; 54% feel that inquiry helps them to improve their self-confidence; and only 40% favor teacher-instructed labs. More than 50% of students think that a mix of inquiry and teacher-instructed

Figure 2. Increase in post-lab discussion from fall 07 to spring 08

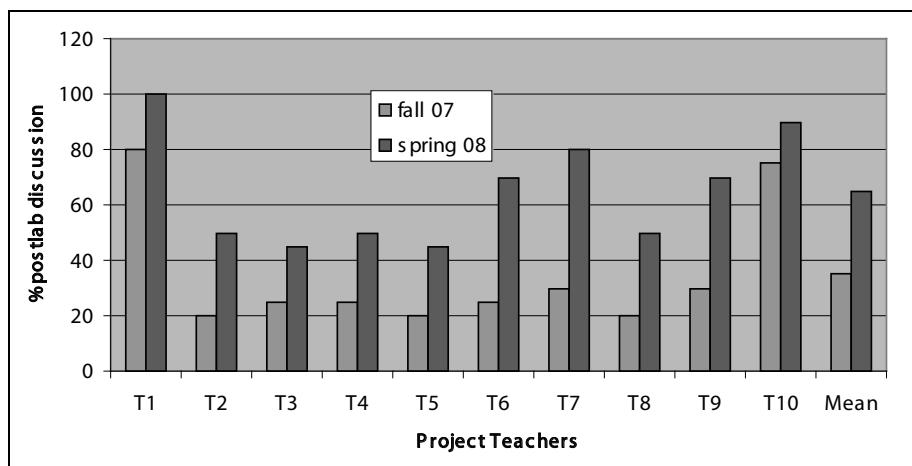
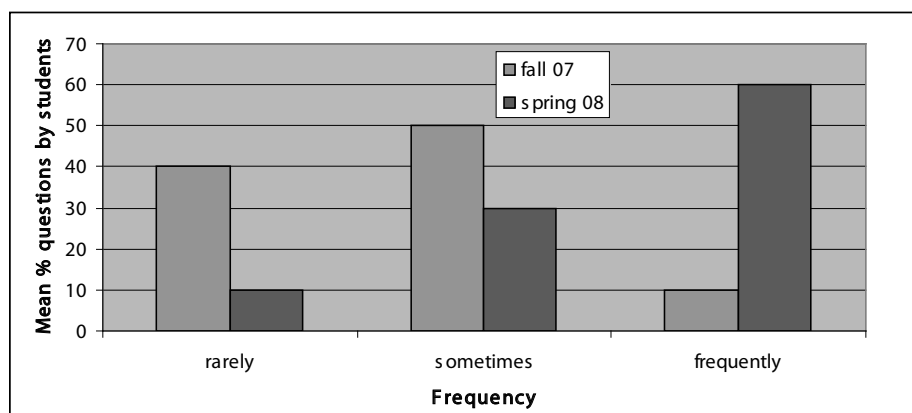


Table 6. Change in % post-lab discussion during fall 07 and spring 08

Teacher/statistics	Fall 2007 % post-lab discussion	Spring 2008 % post-lab discussion	Difference in % post-lab discussion
T1	80	100	20
T2	20	50	30
T3	25	45	20
T4	25	50	25
T5	20	45	25
T6	25	70	45
T7	30	80	50
T8	20	50	30
T9	30	70	40
T10	75	90	25
Mean	35.0	65.0	30.0
SD	22.7	20.0	10.5
Effect size			1.4

Figure 3. Changes in frequency of questions asked by students from fall 07 to spring 08



labs is better than the exclusive use of either strategy. Of these students, 60-70% plan to pursue engineering or science majors in college. However, students tend to think that inquiry is not useful in preparing for graduation tests and college courses, because they have learned from their older peers that hardly any inquiry is done in college courses. These results highlight the necessity of continued emphasis on inquiry as an instructional tool for students at all levels of education.

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